Effect of partial sensitive coating coverage on the limit of detection of microcantilever chemical gas sensors.

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Abstract—The effect of partially coating the microcantilever's length in chemical sensor applications is studied. By only coating near the free end of the cantilever, energy loss associated with the coating's viscoelasticity can be reduced, which, in turns, improve the vibrating beam quality factor without substantially compromising sensitivity. As a result, combinations of coating thickness and beam coverage exist that minimizes the sensor limit of detection (LOD).

I. INTRODUCTION

Microcantilever chemical sensors are typically fabricated by depositing a sensitive coating onto a microcantilever. Such sensors can be very sensitive depending on the coating's affinity for the target species and the coating thickness. Increasing the thickness usually improves sensitivity but reduces the quality factor, thereby increasing the measurement noise. Thus, any effort to improve the sensor's limit of detection (LOD) should take into account the influence of coating thickness on both the sensitivity and the measurement noise.

This study focuses on possible benefits of partially coating the microcantilever's length. In particular, the goal is a reduction in the LOD without any significant drop in sensitivity. To account for the energy losses in the coating, the sensitive material will be modeled as viscoelastic.

Because vibrating microcantilevers are most sensitive to mass loading near the free end, more efficiency may be achieved by depositing the sensitive coating only near the free end. Also, because beam deformations are largest near the support, moving the coating away from the support will help to reduce energy losses associated with the coating's viscoelasticity, thus improving the sensor's quality factor. These ideas provide the motivation to use an analytical model to explore the effects of partial coatings on the performance of microcantilever gas sensors. The sensor characteristics of interest include the sensitivity and the noise occurring in oscillator configuration.

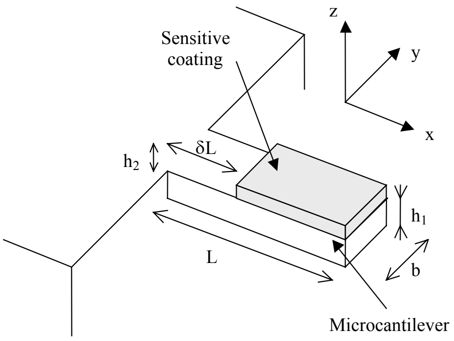

Figure 1. Geometry of the cantilever partially covered by a sensitive coating

II. MODELING

A. Beam model

The equation of motion of an harmonically excited beam in a fluid is [1]:

$$EI\frac{\partial^4 W(x,\omega)}{\partial x^4}+\omega^2\left(m_L+\frac{\pi\rho_0 b^2}{4}\Gamma(\omega)\right)W(x,\omega)=F(x,\omega) \quad (1)$$

where EI is the flexural rigidity, $W(x,\omega)$ is the displacement, $F(x,\omega)$ is the force per unit length, m_L is the beam mass per unit length, ω is the angular frequency, ρ_0 is the fluid mass density, b is the beam width and $\Gamma(\omega)$ is the hydrodynamic function [1].

B. Simple beam model

When considering a beam without sensitive coating, the flexural rigidity of the beam is given by

$$EI = E_1 b h_1^3 / 12 \quad (2)$$

where E_1 is the beam's Young's modulus, h_1 is the beam thickness, and $m_L=\rho_1 b h_1$, with ρ_1 being the beam mass density.

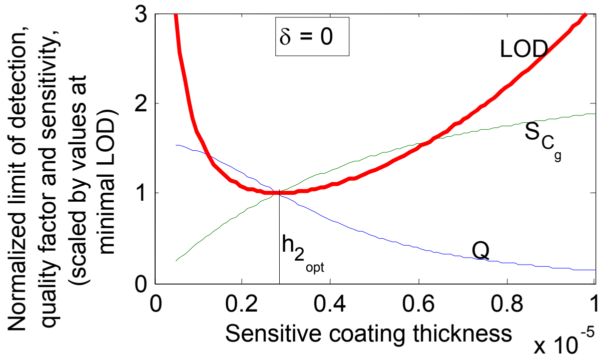

Figure 2. Influence of coating thicknesswith the beam fully covered.

C. *Hybrid beam model*

When the elastic beam is covered by a viscoelastic sensitive coating, the flexural rigidity of the beam is [2]

$$EI = \left(EI\right)^{*} = E_1 I_1 + E_2^{'}(\omega) I_2 + jE_2^{''}(\omega) I_2 \qquad (3)$$

where $E_2^{'}(\omega) + jE_2^{''}(\omega)$ is the complex modulus of the coating, I_1 and I_2 are the moments of inertia of the beam and coating, respectively, which are given in [2], and $m_L = \rho_1 b h_1 + \rho_2 b h_2$, where ρ_2 and h_2 are the mass density and thickness of the sensitive coating.

D. *Partially covered beam model*

To study a beam partially covered with a sensitive coating, equation (1) must be separated into one part describing the bare portion of the beam ($0 \le x \le \delta L$) and another part describing the coated portion ($\delta L < x \le L$) with δ, the *uncoverage factor*, satisfying $0 \le \delta < 1$. Continuity conditions must be imposed at $x = \delta L$ on $W(x,\omega)$, $\dfrac{\partial W(x,\omega)}{\partial x}$, $EI\dfrac{\partial^2 W(x,\omega)}{\partial x^2}$ and $EI\dfrac{\partial W^3(x,\omega)}{\partial x^3}$. Then, by adding the boundary conditions for a clamped-free beam, an analytical expression for $W(x,\omega)$ is obtained.

E. *Limit of detection in oscillator configuration*

By using the sensitivity of the device and the frequency noise, it is possible to calculate the limit of detection (LOD), defined by

$$LOD = 3\frac{\Delta f_{noise}}{S_{C_g}} \ , \qquad (4)$$

where S_{C_g} is the sensitivity of the sensor and Δf_{noise} is the frequency shift due to phase fluctuation in the oscillator loop. The latter is calculated from the Barkhausen condition and is given by [3]

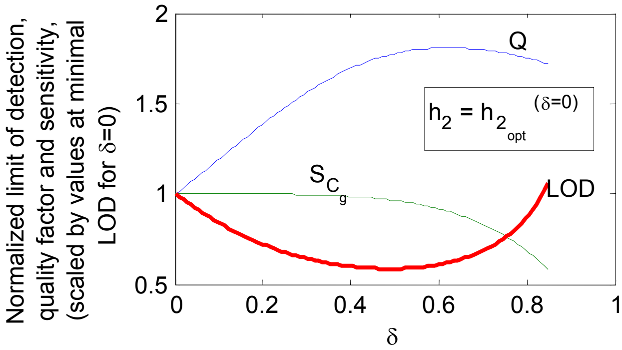

Figure 3. Influence of partial coating coverage. (Coating thickness fixed at optimal thickness corresponding to full coverage.)

$$\Delta f_{noise} \propto f_0 / Q \qquad (5)$$

where f_0 is the resonant frequency and Q is the quality factor.

III. Discussion

By calculating the resonant frequency, the quality factor and the sensitivity for a given beam, the LOD can be determined as a function of the coating thickness and the beam coverage.

From Fig. 2 it can be seen that, for the full coverage case (δ=0), an optimum coating thickness can be found that minimizes the limit of detection. For this thickness, if only the right half of the beam (near the free end) is coated, Fig. 3 shows that significant improvements in the quality factor and LOD may be achieved, while the corresponding drop in sensitivity may be negligible. These results suggest that, in the general case, using thicker coatings near the free end may be preferable to depositing thinner coatings along the entire beam as lower LOD values may be achieved without compromising the sensitivity in a significant manner.

Acknowledgments

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